

1 CLAIMS

2

3 1. Apparatus for manipulating the phase space of
4 at least one charged particle, comprising at least
5 one electrode arranged on a surface and connected to
6 a power supply capable of applying both an
7 alternating current voltage and a direct current
8 voltage so as to form a potential which provides a
9 region of phase space manipulation to one side of
10 the electrode surface, wherein said electrode or
11 electrodes do not surround a charged particle whose
12 phase space is manipulated in use.

13

14 2. The apparatus of claim 1, further comprising
15 pressure control means to control the pressure of
16 the space surrounding the electrodes.

17

18 3. The apparatus of claim 2, wherein the pressure
19 control means comprises a sealable chamber and gas
20 pump means capable of introducing and extracting
21 gases from the chamber.

22

23 4. The apparatus of any of claims 1-3, wherein the
24 power supply is operable to vary the alternating
25 current and direct current voltages applied.

26

27 5. The apparatus of any preceding claim, wherein
28 the power supply is operable to individually alter
29 the amplitude, waveform, and frequency of the
30 alternating current voltage, and is operable to
31 alter the magnitude of the direct current voltage.

32

- 1 6. The apparatus of any preceding claim, wherein
- 2 the potential is an effective potential.
- 3 7. The apparatus of any preceding claim, wherein
- 4 the region of phase space manipulation comprises a
- 5 particle trapping region, wherein a particle is
- 6 constrained in a specific spatial area.
- 7
- 8 8. The apparatus of any preceding claim, wherein
- 9 the region of phase space manipulation comprises a
- 10 particle guide region, wherein a particle's motion
- 11 is restrained by at least one degree of freedom.
- 12
- 13 9. The apparatus of any preceding claim, wherein a
- 14 plurality of electrodes are provided.
- 15
- 16 10. The apparatus of claim 9, wherein the
- 17 electrodes are arranged in an array such that the at
- 18 least one particle is situated to one side of the
- 19 array.
- 20
- 21 11. The apparatus of claim 10, wherein the array is
- 22 substantially planar.
- 23
- 24 12. The apparatus of claim 10, wherein the array is
- 25 hemispherical.
- 26
- 27 13. The apparatus of any of claims 1-8, wherein a
- 28 single electrode is provided, and is surrounded by a
- 29 plane held at a constant potential.
- 30
- 31 14. The apparatus of claim 13, wherein the
- 32 electrode is circular.

1
2 15. The apparatus of claim 13 or claim 14, wherein
3 the plane is earthed.

4
5 16. The apparatus of claim 14 or claim 15, wherein
6 the frequency of alternating current voltage applied
7 to the circular electrode is of a frequency having a
8 period that is less than the time taken for light to
9 pass over the diameter of the circular electrode.

10
11 17. The apparatus of any preceding claim, wherein
12 the voltages applied to adjacent first and second
13 sets of electrodes in a planar array can be varied
14 such that the at least one particle can be moved
15 from the particle trapping region provided by the
16 first set of electrodes to the particle trapping
17 region provided by the second set of electrodes.

18
19 18. The apparatus of claim 17, wherein at least one
20 particle can be moved from a first trapping region
21 provided by a first set of electrodes to a second
22 trapping region provided by a second set of
23 electrodes, wherein the voltages applied to the sets
24 of electrodes can be changed from an initial, to an
25 intermediate and then to a final configuration, and
26 wherein;

27 in an initial configuration, a first set of
28 electrodes is biased to a holding voltage to form a
29 first particle trapping region to trap at least one
30 particle therein, and an adjacent second set of
31 electrodes is biased to zero volts;

1 in an intermediate configuration, both sets of
2 electrodes are biased to the holding voltage to form
3 a merged particle trapping region that traps the at
4 least one particle;

5 in a final configuration, the first set of
6 electrodes is biased to zero volts, and the second
7 set of electrodes is biased to the holding voltage
8 to form a second particle trapping region, that
9 traps the at least one particle.

10

11 19. The apparatus of claim 18, wherein the process
12 of moving at least one particle from a first
13 trapping region provided by a first set of
14 electrodes to a second trapping region provided by a
15 second set of electrodes is repeatable to move the
16 at least one particle along a chosen path on the
17 planar array.

18

19 20. The apparatus of claim 19, wherein the planar
20 array is formed using printed circuit board,
21 lithographic, or focussed ion beam technology.

22

23 21. The apparatus of any of claims 1-16, wherein a
24 series of electrodes are provided, the voltages
25 applied to which are controllable such that the at
26 least one particle can be moved from a first
27 particle trapping region to a second particle
28 trapping region, wherein the first trapping region
29 is larger than the second trapping region.

30

31 22. The apparatus of claim 21, wherein the voltages
32 applied to the electrodes are controllable such that

1 the at least one particle can be moved between a
2 plurality of successively smaller trapping regions.

3
4 23. The apparatus of claim 21 or claim 22, wherein
5 the series of electrodes comprises a plurality of
6 concentrically arranged circular electrodes.

7
8 24. The apparatus of claim 23, wherein, in an
9 initial state, every electrode has a combination of
10 alternating current and direct current voltages
11 applied such that at least one particle is trapped
12 in a first trapping region;

13 the voltage applied to the outer electrode can
14 be changed such that, in an intermediate state, the
15 at least one particle is trapped in a first
16 intermediate trapping region provided by the
17 remaining inner electrodes; and

18 the voltage applied to the electrode adjacent
19 to the outer electrode can be changed such that in a
20 final state, the at least one particle is trapped in
21 a second trapping region provided by the innermost
22 electrode.

23
24 25. The apparatus of claim 24, wherein, in the
25 transitions from the initial to intermediate and the
26 intermediate to final states, the outer and adjacent
27 electrodes respectively are set to zero volts.

28
29 26. The apparatus of claim 24 or claim 25, wherein
30 a plurality of electrodes can each provide a further
31 intermediate trapping region, such that, between the
32 initial state and the final state, the at least one

1 particle passes through a plurality of intermediate
2 states, being trapped in successively smaller
3 intermediate trapping regions.

4
5 27. The apparatus of any of claims 21-23, wherein,
6 in an initial state, an outermost electrode has a
7 first combination of alternating current and direct
8 current voltages applied, and a background voltage
9 is applied to the remaining electrodes such that, in
10 an initial state, at least one particle is trapped
11 in a first trapping region;

12 the electrode adjacent to the outer electrode
13 can be set to the first combination of voltages and
14 the background voltage is applied to the outer
15 electrode such that, in an intermediate state, the
16 at least one particle is trapped in a first
17 intermediate trapping region; and

18 the innermost electrode can be set to the first
19 combination of voltages and the background voltage
20 is applied to the adjacent electrode such that, in a
21 final state, the at least one particle is trapped in
22 a second trapping region.

23

24 28. The apparatus of claim 27, wherein the
25 background voltage is zero volts.

26

27 29. The apparatus of claim 27 or claim 28, wherein
28 a plurality of electrodes is provided such that,
29 between the initial state and the final state, the
30 at least one particle passes through a plurality of
31 intermediate states, being trapped in successively
32 smaller intermediate trapping regions.

1

2 30. The apparatus of any of claims 23-29 when
3 dependent on claim 23, wherein the innermost
4 electrode is provided with an aperture; arranged
5 such that:

6 when the at least one particle is in the final
7 state, a voltage is applied to the aperture such
8 that the at least one particle is urged through the
9 aperture.

10

11 31. The apparatus of claim 30, wherein each side of
12 the aperture is differentially pumped so that a gas
13 passing through the aperture undergoes a supersonic
14 expansion, so as to cool the particles that are
15 urged through the aperture.

16

17 32. The apparatus of any preceding claim, wherein
18 the voltages applied to an electrode are such that
19 one type of charged particle can be distinguished
20 from another.

21

22 33. The apparatus of claim 32, wherein different
23 types of charged particle are trapped at different
24 distances perpendicularly from the surface of the
25 electrode.

26

27 34. The apparatus of claim 33, wherein the distance
28 is dependent on the charge and/or mass of the
29 charged particle.

30

31 35. The apparatus of claim 34, wherein a first type
32 of charged particle is trapped at a first

1 perpendicular distance from the electrode, and a
2 second type of charged particle is trapped at a
3 second perpendicular distance from the electrode,
4 wherein the mass of the first charged particle is
5 greater than the mass of the second charged
6 particle, and the second perpendicular distance is
7 greater than the first perpendicular distance.

8
9 36. The apparatus of claim 35, wherein at least one
10 particle trapped at the second perpendicular
11 distance is subject to the potential formed by a
12 voltage sequence applied to a second set of
13 electrodes.

14
15 37. The apparatus of claim 36, wherein the voltage
16 sequence applied to the second set of electrodes is
17 such as to transport said at least one particle from
18 one trapping region to another along a predetermined
19 path.

20
21 38. The apparatus of claim 36 or claim 37, wherein
22 the dimensions of the second set of electrodes are
23 of a much larger scale than the dimensions of the
24 trap electrode.

25
26 39. The apparatus of any of claims 32-38, wherein
27 an aperture is provided on an electrode such that
28 the type of particle that is closest to the surface
29 of the electrode can pass through the aperture.

30
31 40. The apparatus of claim 39, wherein each side of
32 the aperture is differentially pumped so that a gas

1 passing through the aperture undergoes a supersonic
2 expansion, so as to cool the particles that are
3 urged through the aperture.
4

5 41. The apparatus of any preceding claim, wherein
6 the voltages applied to an electrode can be changed
7 such that a trapped particle moves in a direction
8 perpendicular to the plane of the electrode.
9

10 42. The apparatus of claim 41, wherein at least one
11 trapped particle can be lowered to a region where it
12 will interact with at least one other particle; and
13 the particles that result from the interaction
14 can then be raised up again, together with particles
15 that have not interacted.
16

17 43. The apparatus of claim 41 or claim 42, wherein
18 the electrode is formed with an aperture and the
19 applied voltage can be changed to bring a particle
20 close to the aperture; and

21 a voltage is applied to the aperture such that
22 the particle is urged through the aperture.
23

24 44. The apparatus of claim 43, wherein each side of
25 the aperture is differentially pumped so that a gas
26 passing through the aperture undergoes a supersonic
27 expansion, so as to cool the particles that are
28 urged through the aperture.
29

30 45. The apparatus of any of claims 41-44, wherein
31 an array of electrodes is provided, the voltages
32 applied to which trap a first type of particle which

1 can interact with a second type of particle, to form
2 a reactant particle which falls to the bottom of a
3 trap and is swept away through an extraction hole.

4
5 46. The apparatus of claim 45, wherein the array of
6 electrodes further comprises at least one aperture
7 for the extraction of trapped particles.

8
9 47. The apparatus of claim 46, wherein each
10 electrode comprises one aperture.

11
12 48. The apparatus of claim 47, wherein the reactant
13 particle is accelerated through a potential and
14 detected so that the position of the original first
15 type of particle can be detected.

16
17 49. A method for manipulating the phase space of at
18 least one charged particle, wherein a combination of
19 alternating current and direct current voltages
20 applied to an electrode forms a potential which
21 provides a region of phase space manipulation, and
22 wherein the at least one charged particle is
23 situated to one side of the electrode surface,
24 wherein said electrode or electrodes do not surround
25 a charged particle whose phase space is manipulated
26 in use.

27
28 50. The method of claim 49, further comprising the
29 step of controlling the pressure of the space
30 surrounding the electrodes.

31

1 51. The method of claim 50, wherein the pressure
2 control means comprises a sealable chamber and gas
3 pump means capable of introducing and extracting
4 gases from the chamber.

5
6 52. The method of any of claims 49-51, wherein the
7 power supply is operable to vary the alternating
8 current and direct current voltages applied.

9
10 53. The method of any of claims 49-52, wherein the
11 power supply is operable to individually alter the
12 amplitude, waveform, and frequency of the
13 alternating current voltage, and is operable to
14 alter the magnitude of the direct current voltage.

15
16 54. The method of any of claims 49-53, wherein the
17 potential is an effective potential.

18
19 55. The method of any of claims 49-54, wherein the
20 region of phase space manipulation comprises a
21 particle trapping region, wherein a particle is
22 constrained in a specific spatial area.

23
24 56. The method of any of claims 49-55, wherein the
25 region of phase space manipulation comprises a
26 particle guide region, wherein a particle's motion
27 is restrained by at least one degree of freedom.

28
29 57. The method of any of claims 49-56, wherein a
30 plurality of electrodes are provided.

31

1 58. The method of claim 57, wherein the electrodes
2 are arranged in an array such that the at least one
3 particle is situated to one side of the array.
4

5 59. The method of claim 58, wherein the array is
6 substantially planar.
7

8 60. The method of claim 58, wherein the array is
9 hemispherical.
10

11 61. The method of any of claims 49-56, wherein a
12 single electrode is provided, and is surrounded by a
13 plane held at a constant potential.
14

15 62. The method of claim 61, wherein the electrode
16 is circular.
17

18 63. The method of claim 61 or claim 62, wherein the
19 plane is earthed.
20

21 64. The method of claim 62 or claim 63, wherein the
22 frequency of alternating current voltage applied to
23 the circular electrode is of a frequency having a
24 period that is less than the time taken for light to
25 pass over the diameter of the circular electrode.
26

27 65. The method of any of claims 49-64, wherein the
28 voltages applied to adjacent first and second sets
29 of electrodes in a planar array can be varied such
30 that the at least one particle can be moved from the
31 particle trapping region provided by the first set

1 of electrodes to the particle trapping region
2 provided by the second set of electrodes.

3
4 66. The method of claim 65, wherein at least one
5 particle is moved from a first trapping region
6 provided by a first set of electrodes to a second
7 trapping region provided by a second set of
8 electrodes, wherein the voltages applied to the sets
9 of electrodes is changed from an initial, to an
10 intermediate and then to a final configuration, and
11 wherein;

12 in an initial configuration, a first set of
13 electrodes is biased to a holding voltage to form a
14 first particle trapping region to trap at least one
15 particle therein, and an adjacent second set of
16 electrodes is biased to zero volts;

17 in an intermediate configuration, both sets of
18 electrodes are biased to the holding voltage to form
19 a merged particle trapping region that traps the at
20 least one particle;

21 in a final configuration, the first set of
22 electrodes is biased to zero volts, and the second
23 set of electrodes is biased to the holding voltage
24 to form a second particle trapping region, that
25 traps the at least one particle.

26

27 67. The method of claim 66, wherein the process of
28 moving at least one particle from a first trapping
29 region provided by a first set of electrodes to a
30 second trapping region provided by a second set of
31 electrodes is repeatable to move the at least one
32 particle along a chosen path on the planar array.

1

2 68. The method of claim 67, wherein the planar
3 array is formed using printed circuit board,
4 lithographic, or focussed ion beam technology.

5

6 69. The method of any of claims 49-64, wherein a
7 series of electrodes are provided, the voltages
8 applied to which are controllable such that the at
9 least one particle can be moved from a first
10 particle trapping region to a second particle
11 trapping region, wherein the first trapping region
12 is larger than the second trapping region.

13

14 70. The method of claim 69, wherein the voltages
15 applied to the electrodes are controllable such that
16 the at least one particle can be moved between a
17 plurality of successively smaller trapping regions.

18

19 71. The method of claim 69 or claim 70, wherein the
20 series of electrodes comprises a plurality of
21 concentrically arranged circular electrodes.

22

23 72. The method of claim 71, wherein, in an initial
24 state, every electrode has a combination of
25 alternating current and direct current voltages
26 applied such that at least one particle is trapped
27 in a first trapping region;

28 the voltage applied to the outer electrode is
29 changed such that, in an intermediate state, the at
30 least one particle is trapped in a first
31 intermediate trapping region provided by the
32 remaining inner electrodes; and

1 the voltage applied to the electrode adjacent
2 to the outer electrode is changed such that in a
3 final state, the at least one particle is trapped in
4 a second trapping region provided by the innermost
5 electrode.

6
7 73. The method of claim 72, wherein, in the
8 transitions from the initial to intermediate and the
9 intermediate to final states, the outer and adjacent
10 electrodes respectively are set to zero volts.

11
12 74. The method of claim 72 or claim 73, wherein a
13 plurality of electrodes each provide a further
14 intermediate trapping region, such that, between the
15 initial state and the final state, the at least one
16 particle passes through a plurality of intermediate
17 states, being trapped in successively smaller
18 intermediate trapping regions.

19
20 75. The method of any of claims 69-71, wherein, in
21 an initial state, an outermost electrode has a first
22 combination of alternating current and direct
23 current voltages applied, and a background voltage
24 is applied to the remaining electrodes such that, in
25 an initial state, at least one particle is trapped
26 in a first trapping region;

27 the electrode adjacent to the outer electrode
28 is set to the first combination of voltages and the
29 background voltage is applied to the outer electrode
30 such that, in an intermediate state, the at least
31 one particle is trapped in a first intermediate
32 trapping region; and

1 the innermost electrode is set to the first
2 combination of voltages and the background voltage
3 is applied to the adjacent electrode such that, in a
4 final state, the at least one particle is trapped in
5 a second trapping region.

6
7 76. The method of claim 75, wherein the background
8 voltage is zero volts.

9
10 77. The method of claim 75 or claim 76, wherein a
11 plurality of electrodes is provided such that,
12 between the initial state and the final state, the
13 at least one particle passes through a plurality of
14 intermediate states, being trapped in successively
15 smaller intermediate trapping regions.

16
17 78. The method of any of claims 71-77 when
18 dependent on claim 71, wherein the innermost
19 electrode is provided with an aperture; and
20 when the at least one particle is in the final
21 state, a voltage is applied to the aperture such
22 that the at least one particle is urged through the
23 aperture.

24
25 79. The method claim 78, wherein each side of the
26 aperture is differentially pumped so that a gas
27 passing through the aperture undergoes a supersonic
28 expansion, so as to cool the particles that are
29 urged through the aperture.

30
31 80. The method of any of claims 49-79, wherein the
32 voltages applied to an electrode are such that one

1 type of charged particle can be distinguished from
2 another.

3
4 81. The method of claim 80, wherein different types
5 of charged particle are trapped at different
6 distances perpendicularly from the surface of the
7 electrode.

8
9 82. The method of claim 81, wherein the distance is
10 dependent on the charge and/or mass of the charged
11 particle.

12
13 83. The method of claim 82, wherein a first type of
14 charged particle is trapped at a first perpendicular
15 distance from the electrode, and a second type of
16 charged particle is trapped at a second
17 perpendicular distance from the electrode, wherein
18 the mass of the first charged particle is greater
19 than the mass of the second charged particle, and
20 the second perpendicular distance is greater than
21 the first perpendicular distance.

22
23 84. The method of claim 83, wherein at least one
24 particle trapped at the second perpendicular
25 distance is subject to the potential formed by a
26 voltage sequence applied to a second set of
27 electrodes.

28
29 85. The method of claim 84, wherein the voltage
30 sequence applied to the second set of electrodes is
31 such as to transport said at least one particle from

1 one trapping region to another along a predetermined
2 path.

3
4 86. The method of claim 84 or claim 85, wherein the
5 dimensions of the second set of electrodes are of a
6 much larger scale than the dimensions of the trap
7 electrode.

8
9 87. The method of any of claims 80-86, wherein an
10 aperture is provided on an electrode such that the
11 type of particle that is closest to the surface of
12 the electrode can pass through the aperture.

13
14 88. The method of claim 87, wherein each side of
15 the aperture is differentially pumped so that a gas
16 passing through the aperture undergoes a supersonic
17 expansion, so as to cool the particles that are
18 urged through the aperture.

19
20 89. The method of any of claims 49-88, wherein the
21 voltages applied to an electrode can be changed such
22 that a trapped particle moves in a direction
23 perpendicular to the plane of the electrode.

24
25 90. The method of claim 89, wherein at least one
26 trapped particle can be lowered to a region where it
27 will interact with at least one other particle; and
28 the particles that result from the interaction
29 can then be raised up again, together with particles
30 that have not interacted.

31

1 91. The method of claim 89 or claim 90, wherein the
2 electrode is formed with an aperture and the applied
3 voltage can be changed to bring a particle close to
4 the aperture; and

5 a voltage is applied to the aperture such that
6 the particle is urged through the aperture.

7
8 92. The method of claim 91, wherein each side of
9 the aperture is differentially pumped so that a gas
10 passing through the aperture undergoes a supersonic
11 expansion, so as to cool the particles that are
12 urged through the aperture.

13
14 93. The method of any of claims 89-92, wherein an
15 array of electrodes is provided, the voltages
16 applied to which trap a first type of particle which
17 can interact with a second type of particle, to form
18 a reactant particle which falls to the bottom of a
19 trap and is swept away through an extraction hole.

20
21 94. The method of claim 93, wherein the array of
22 electrodes further comprises at least one aperture
23 for the extraction of trapped particles.

24
25 95. The method of claim 94, wherein each electrode
26 comprises one aperture.

27
28 96. The method of claim 95, wherein the reactant
29 particle is accelerated through a potential and
30 detected so that the position of the original first
31 type of particle can be detected.

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